The Physics Behind Flight

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Force
A Desire to move
Sum of all Forces = mass x acceleration

General Concept:

A force is often better known to kids as a push or a pull (contact force). When John is pushing the wagon up the hill, he is exerting a force on the wagon and hence the wagon moves. The more subtle aspect of forces, however, comes in the idea of counter forces. Kim, standing on top of the hill, is exerting a force on the ground. That is, she has a certain weight (the force exerted on an object by a gravitational field). Fortunately for her, however, the ground is exerting exactly the same force upward, so the two forces balance out each other. The sum of all the forces (the net force) exerted on Kim is zero and she does not move.

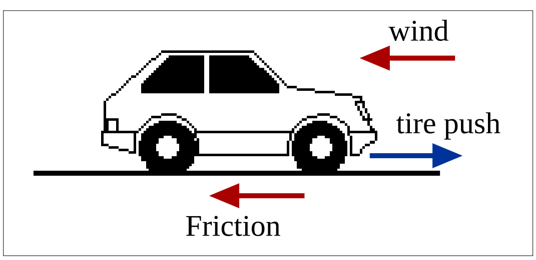
Now, it is a little-known fact that Kim is actually standing on a bunch of branches covering a hole. John, who dug the hole, tosses Kim a heavy ball. Now the weight of Kim and the ball is greater than the counter-force that can be exerted by the branches, the sum of all the forces are no longer zero - and Kim goes flying into the hole. She accelerates downward.

General Facts:

You can exert a force by pushing or pulling something
If all the forces on an object are equal and opposite, the object will not accelerate.
If the forces are not equal and opposite, the object will accelerate in the direction of the net force.

Example: the car
Pushing the gas pedal translates to the tires pushing the car forward against the road.
If the tires are pushing with a force that exactly counteracts all other forces (wind resistance, tire friction*, etc.) the car will neither accelerate nor decelerate.
(Sum of forces = 0, therefore acceleration = 0)
If the wind resistance, tire friction, etc. exceed the tire push, the car will slow down.
(Sum of forces < 0, therefore acceleration < 0)
If the tire push is greater than the wind resistance etc., the car will accelerate.
(Sum of forces > 0, therefore acceleration > 0)

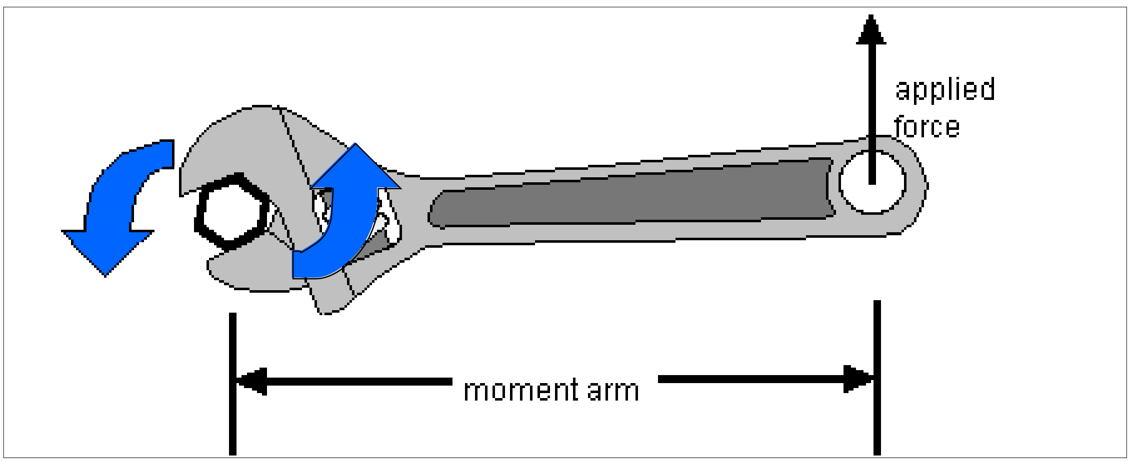
* friction is the force between two things when they make contact



Torque
A desire to rotate
Sum of all Torques = rotational inertia x angular acceleration
Torque = Force x Moment Arm

General Concept:
A torque is often better known to kids as a rotation. When Jill tightens the bolt with a wrench, she is exerting a torque on the bolt. Like the force, if all torques are equal, she will be unable to tighten the bolt. If the torque she exerts is greater than the counter torque of the friction in the bolt, the bolt will rotate (tighten).

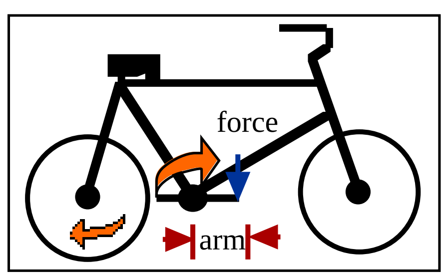
Torque and force are directly linked. The more Jill pushes (applied force) at the edge of the wrench, the more torque she applies and the tighter the bolt becomes. However, it is not just force that makes a difference. The further out from the bolt she holds the wrench, the more torque she applies, and the tighter the bolt. Therefore, the torque must be related to both the push (force) and distance from the center of rotation that the force is applied. This distance is called the **moment arm**. A similar example is a door. The further away from the hinges you push on a door, the more torque you are applying, and the easier it is to open.



General Facts:
You can exert a torque by pushing or pulling something a given distance from the center of rotation. You must push perpendicular to the moment arm. If all the torques on an object are equal and opposite, the object will not rotate faster or more slowly (no angular acceleration). If the torques are not equal and opposite, the object will rotate faster in the direction of the net torque.

Example: the pedal on the bike
Pushing the bike pedal translates into a torque which rotates the tires. If you are exerting a torque that exactly counteracts all other torques (frictional torques, etc.) the tire (pedal) will neither accelerate nor decelerate.

(Torque sum=0, therefore angular acceleration=0)
if the frictional torques etc. exceed the torque you exert, the tire (pedal) will slow down.
(Torque sum<0, therefore angular acceleration<0)
if your exerted torque is greater than the frictional torque etc., the tire (pedal) will accelerate.
(Torque sum>0, therefore angular acceleration>0)



Energy

The capacity to do work

Sum of all energy = 0

General Concept:

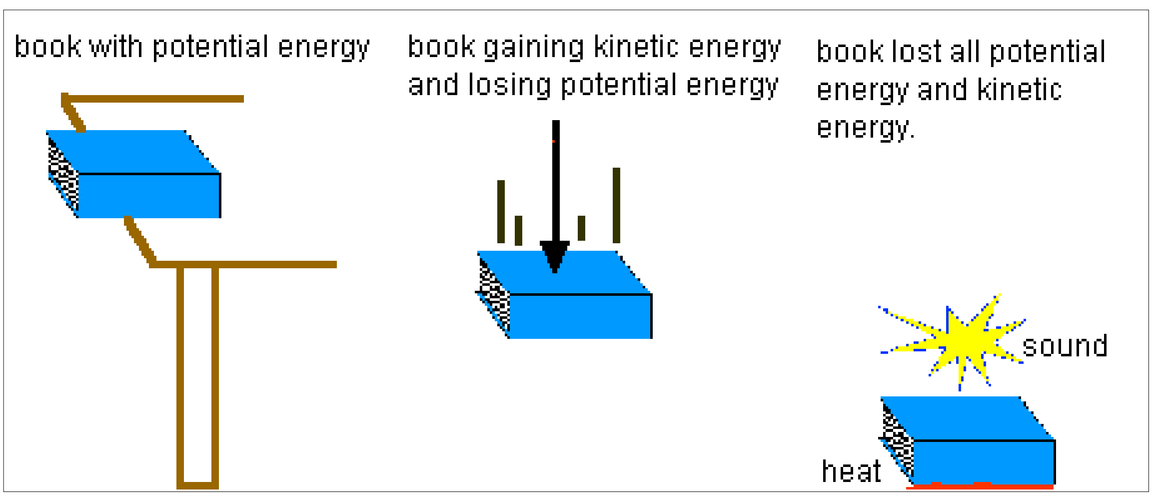
The total amount of energy must stay constant. That means that if you use energy to do something, it is at the cost of something else. For instance, Dave the Olympic diver uses energy that he got from food to climb to the top of the high dive. He has converted that food energy (calories) into potential energy. He jumps off the board (after exerting as big a torque as possible on the board tip) and converts this potential energy into kinetic energy (energy of motion) as he accelerates down to the pool. Note that he has unequal forces exerted on him - his weight pulling him down and air resistance trying to keep him up - and since they are unequal (his weight is a larger force), he accelerates down until he hits the water. When he hits the water, he dissipates the energy into the water, climbs out, and does the whole thing over again.

There are numerous forms that energy can take. The most common are:
Potential energy (energy associated with height) = weight x height
Kinetic energy (energy associated with movement) = 1/2 x mass x velocity x velocity
Photon energy (energy associated with light)
Electricity (energy associated with the motion of electrons)
Heat (energy associated with the motion of molecules, measured by temperature)
Sound (energy associated with acoustics)

General Facts:

Energy is conserved; that is, you can only transfer energy from one form to another.
Unlike force and torque, energy has no direction associated with it.

Example: dropping a book
The book on the shelf has some potential energy associated with its height.
As the book falls off the shelf it looses height (potential energy) and increases in speed (kinetic energy).
(Decrease in potential energy = increase in kinetic energy)
When it hits the ground it stops (loses kinetic energy) but makes a noise (acoustic energy).
(Loss of kinetic energy = increase in acoustic energy (and some heat))



Even though energy is conserved, you can not always control the direction or form that it takes. For instance, no amount of yelling at the book will lift it back up to its original height.

Pressure

The exertion of force upon a surface

Pressure = force / area of surface

General Concept:

Pressure is often a difficult concept for the students to grasp. It is the total force exerted per unit area.* Fred the fisherman feels this pressure as he walks through the stream searching for that ever-elusive fish that "got away." The boot feels tighter under water - because the water is applying a greater pressure at the bottom of the stream than at the top.

Although the pressure at any point is equal in all directions, the force resulting from a pressure always acts perpendicular to the surface. When you put your hand out the car window, air pressure in front of your hand pushes the hand back with a greater force than the force due to air pressure behind the hand, therefore accelerating the hand backward.

When you stand on the balls of your feet, they will start to hurt quickly. Although the force is the same (your weight), the area that the force is acting on has gotten smaller, and you feel a greater pressure.

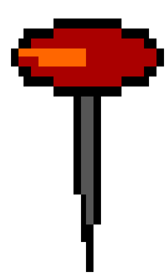
There is pressure on you all of the time. The weight of the atmosphere, divided by the surface area of the earth, is called the "atmospheric pressure." When you go on top of a mountain the pressure is less because there is less atmosphere above you to push down on you.

General Facts:

Pressure can result from molecules of air (or water) hitting you - there is no pressure in outer space where there are no molecules.
The force resulting from a pressure is perpendicular to the surface.
A fluid always wants to move from a high pressure to a low pressure.

Example: the nail

just like the balls of the feet example: same force, different pressures
push both the head and the tip down onto your finger
since the tip area is much smaller than the head area, the pressure is much greater when you press the tip onto your finger - and therefore hurts more
this is why you want to sharpen your knives. The sharper the knife, the smaller the area, the greater the pressure - and the easier it is to cut.



*unit area is a 1x1 area in whatever units you are working in. i.e. inches would be 1"x1" square.
example: atmospheric pressure is 14.7 psi: 14.7 pounds of force on every square inch.

Velocity

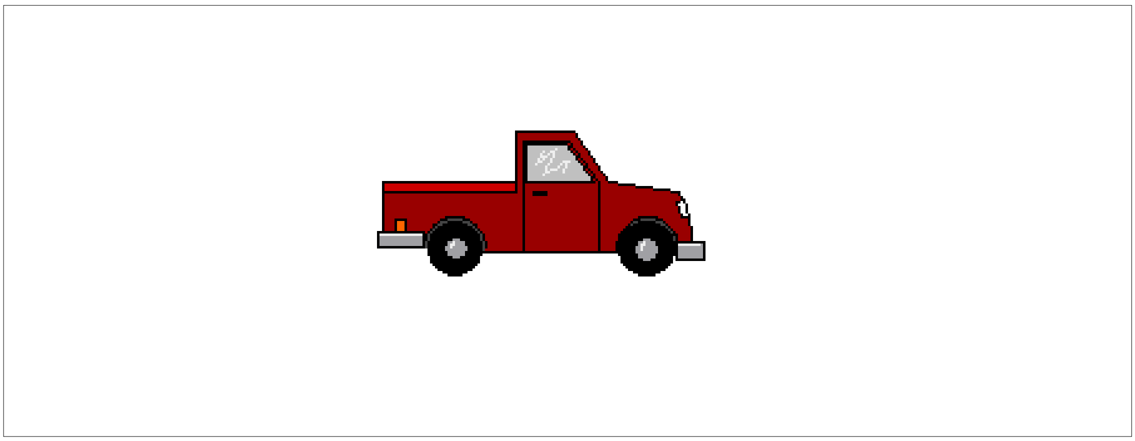
Motion

average velocity = distance traveled / elapsed time

General Concept:
A velocity is often better known to kids as a speed. The faster Becky runs, the greater her velocity.

General Facts:
velocity has a direction associated with it

Example: toy car
measure out a distance on the floor
time how long it takes for a toy car to go the length of the floor
find the average velocity of the car (distance covered/time taken)



Bernoulli's Theorem

How pressure and velocity interact

static pressure + dynamic pressure = total pressure = constant

static pressure + 1/2 x density x velocity^2 = total pressure = constant

General Concept:

The Bernoulli effect is simply a result of the conservation of energy. Energy can be stored as an increase in pressure or as a change in velocity. Although one can take into account changes in energy due to height changes (potential energy), or energy losses due to friction, etc., we will assume that they are small for now.

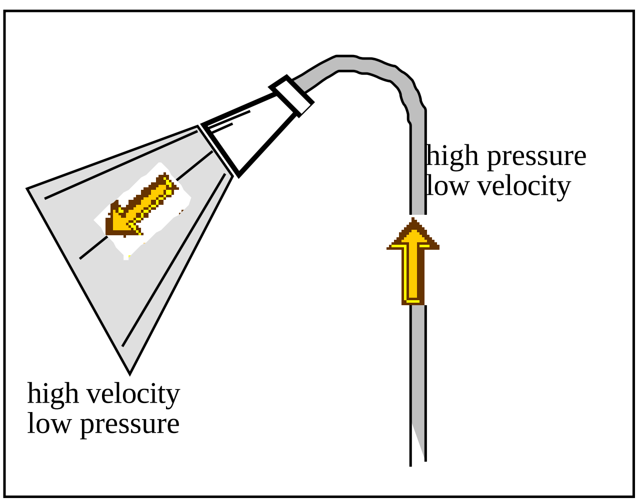
General Facts:

• If you slow a flow down, the pressure will go up.
• You can speed up a flow by dropping the pressure.

In the real case, friction plays a large role - a lot of times you must have a large pressure drop (decrease in pressure) just to overcome friction. This is the case in your house. Most water pipes have small diameters (large friction), hence the need for "water pressure" - it is the energy from that pressure drop that goes to friction.

Example: the showerhead

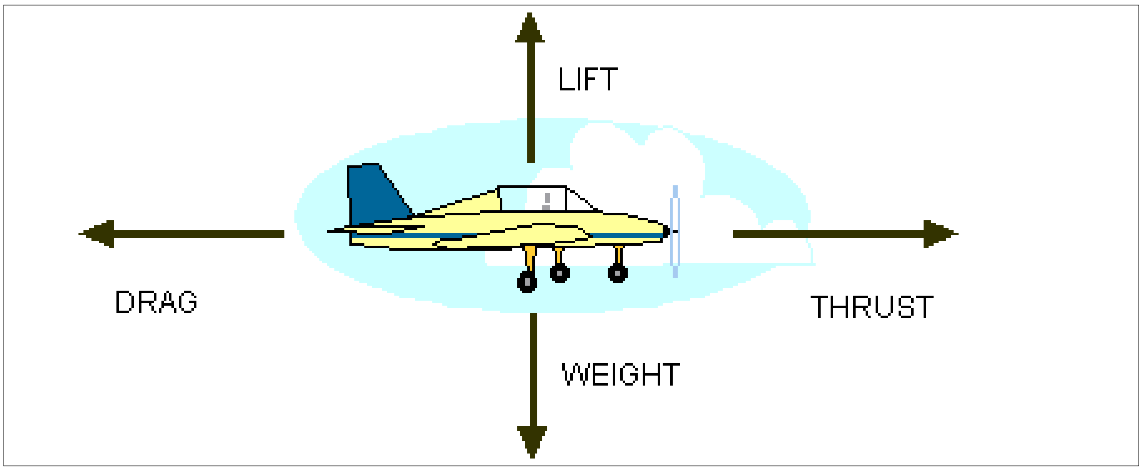
A showerhead (if you have a fancy one) has a number of different operation modes. If you go for the "massage" mode, you are moving a little water fast. For the "lite shower," you are moving a lot of water slowly. It takes the same amount of energy to move a little water fast as it does to move a lot of water slowly. this is the amount of energy you have due to your "water pressure."



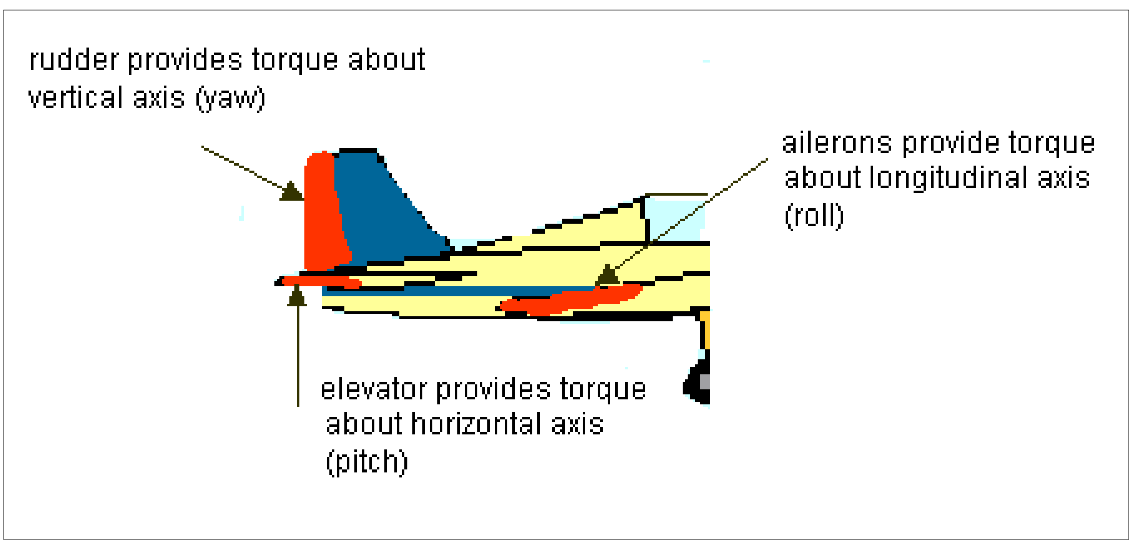
Lift and Drag

Two of the four forces on an airplane

General Concept:
Just like in the first page of this manual, an airplane flies by balancing forces. If the trust of the airplane's engines is greater than the force of the wind (drag force), the plane will go forward. Likewise, if the lifting force of the wings is greater than the weight of the plane (the force of gravity), the plane will rise in the air. Therefore, to make the airplane work, one must have sufficiently powerful engines to push the plane through the air, and have designed wings to lift the plane in the air. Once in the air, airplanes maneuver by moving control surfaces which provide torques about the center of mass of the airplane. These torques will rotate the aircraft in the appropriate direction.



Forces on an airplane



Control surfaces on an airplane

Lift

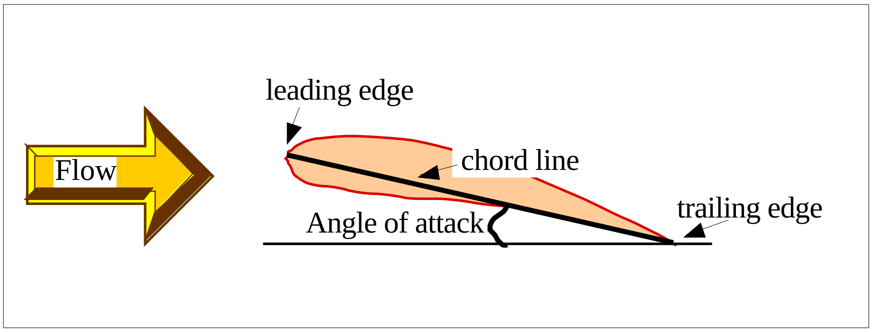
Upward Force (good!)

General Concept

The force of the wind on the plane can be divided into two components: a component pushing the plane up and a component pushing the plane back. The upward force, the lift force, is what keeps the plane in the air. In fact, the pilot can change the lift force: getting a lot of lift at takeoff (need to accelerate the plane upward) and less lift during cruise (just need to overcome the weight of the plane.

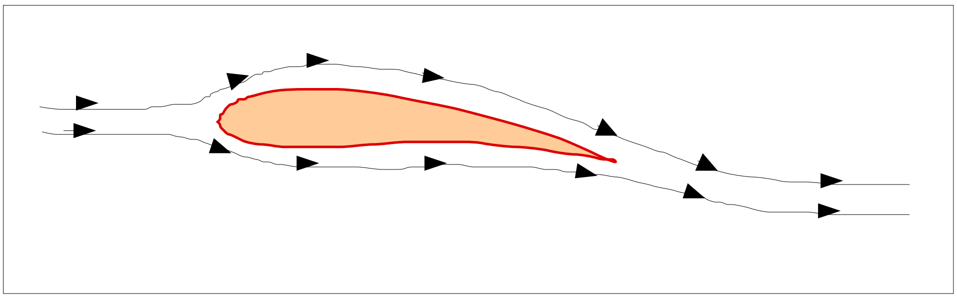
Before delving into what causes lift, it is a good idea to define some parts of the wing:

Definitions: *leading edge:* the part of the wing that sees the air first (faces the direction of motion)
trailing edge: the rear edge of a wing
chord line: the line joining the leading edge and trailing edge
angle of attack: the angle between the chord line and the incoming wind.



Wing definitions

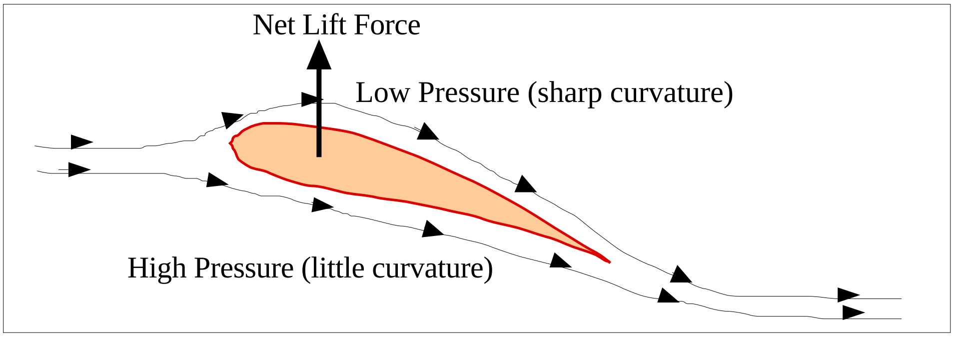
A *streamline* of a fluid flow is like a snapshot of the flow at any given time. The velocity of the flow is always tangent to the streamline.



Streamlines around an airfoil

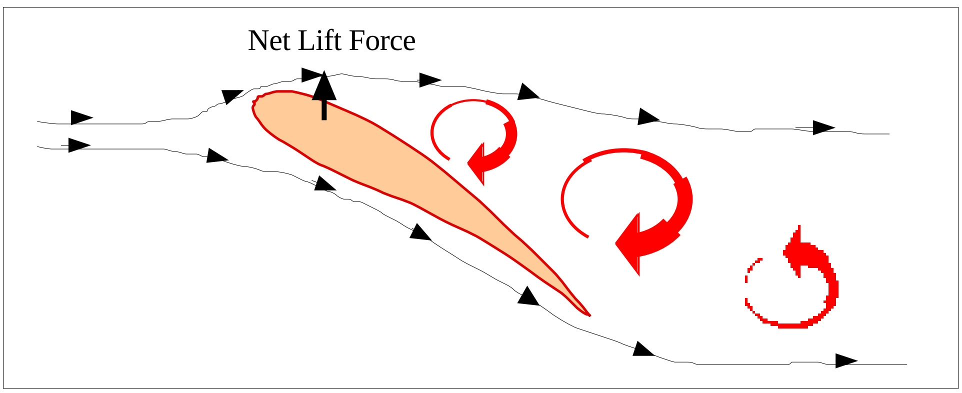
Streamlines vs. Pressure:

Streamlines actually tell one a lot about the flow. They show you how the flow is moving around an object. They also show you what the pressure looks like everywhere around the object. It turns out that if there is curvature in the streamlines, then there must be a change in pressure. In fact, it is that change in pressure that is keeping the streamlines curved. If there where to pressure difference, then the streamlines would be straight. Further, the lowest pressure is always at the center of curvature. Therefore, sharp curves correspond to low pressures. So if I can design a shape that has sharp curves on the top and smooth on the bottom, then I will get a pressure difference across that surface. This is how the airfoil works.



Pressure difference causes the net lift force

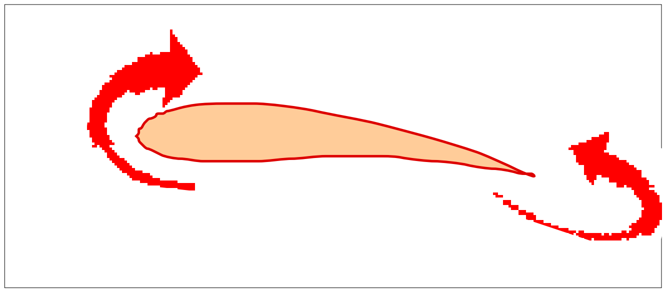
As one increase the angle of attack of the airfoil, this curvature over the top becomes greater - causing a greater pressure difference and therefore a greater lift force. Eventually, however, if the curvature becomes too great, the flow separates off the wing and you have stall. With stall comes a drastic change in the curvature and therefore the pressure difference and therefore the lift. Stall usually causes the pilot to loose some control until he decreases the angle of attack and regains substantial lift (all planes have stall sirens that go off when the wings stall).



Stall: too high an angle of attack reduces the lift (and curvature)

Another way to explain lift is through circulation:

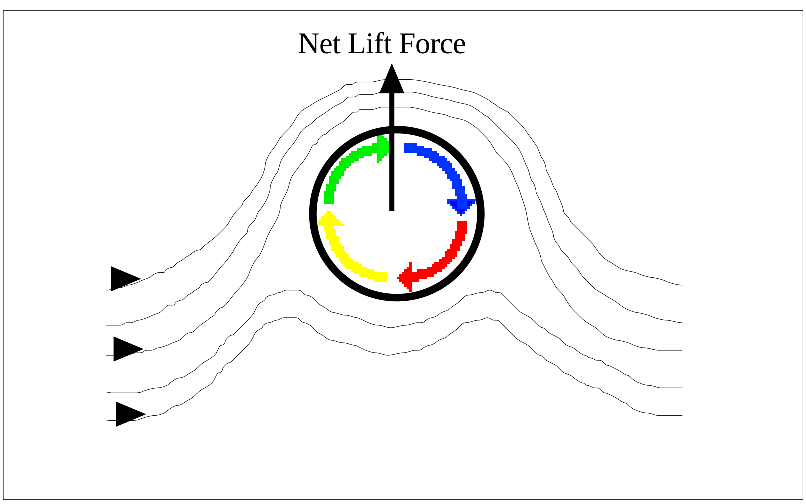
Initially, air flowing under the wing tries to “curl“ around the trailing edge and around to the top surface. Such a quick turn requires an infinitely high velocity, which is not desirable by nature. Viscosity (friction) causes the flow to begin to leave the trailing edge smoothly. This condition at the trailing edge results in the “curl,” or the **circulation,** to be shed. Because energy is conserved, another circulation in the opposite direction becomes attached to the wing. The same effect can be observed when moving a spoon through a teacup. Note the two regions of circulation - in opposite directions.



Circulation of opposite direction at the start of the airflow over an airfoil

The trailing edge circulation gets left behind as the wing moves forward, but the clockwise circulation remains attached to the wing. This circulation causes the flow over the top of the wing to be faster than the flow over the bottom of the wing. Because of Bernoulli's theorem, the faster flow causes the pressure on the top surface of the wing to be low. This is what causes lift. The two circulation regions can be seen by running an airfoil through a pan of water.

Lift can occur on objects other than wings. Lift is responsible for golf balls slicing into the woods and top spin lobs landing in the tennis court. To illustrate the top-spin lob, imagine the ball in the picture below traveling to the right while also spinning clockwise. The balls spinning motion is adding circulation to an otherwise uniform flow. It is the addition of these two types of flow - circulation and uniform flow - that creates lift. You need them both. The spinning of the bottom of the ball tends to add velocity to the flow around the ball. Because of the Bernoulli effect, this decreases the pressure there, and the ball tends to go downward (negative lift). This is why top-spins tend to land in the court.



Drag

Force against direction of motion (bad!)

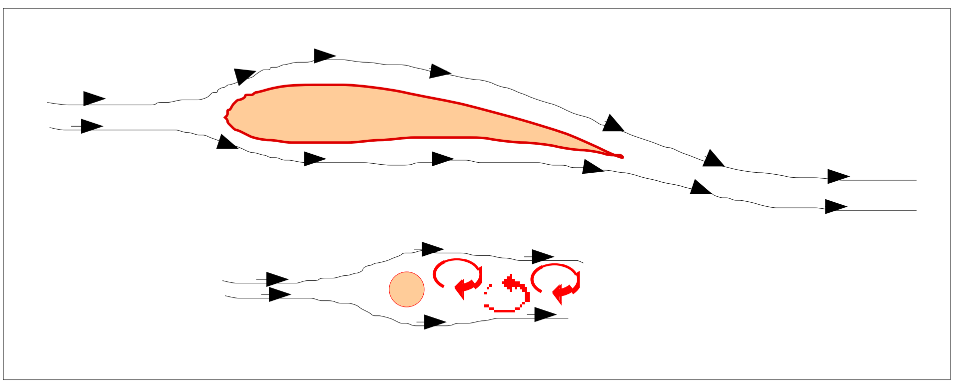
General Concept

Drag is the force that slows the airplane down. It is defined as all forces opposite the direction of motion of the plane. These forces are usually one of two types: pressure drag and skin friction drag.

Pressure Drag occurs when the air flow separates from the surface. If you stick your palm out and swing it through the air (thumb towards ceiling and pinky closer to floor - that is give it a slight angle of attack), your hand experiences pressure drag, much like the picture of the wire below.

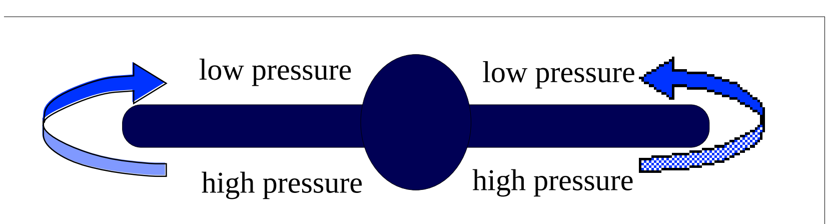
Skin Friction Drag is the drag due to the friction between the air and the surface moving through the air. If you "slice" your hand through the air, palm parallel to the floor, your hand is experiencing mainly skin friction drag (the surface of an airplane wing is also called a skin). The friction is experiences because your hand tends to try to pull the air along with it.

A wing can have the same drag as a wire that is much smaller than the wing. The difference is that the wing has mostly skin friction drag, and the wire has mostly pressure drag. Can you see why airplanes no longer have lots of wires like the old bi-planes used to?

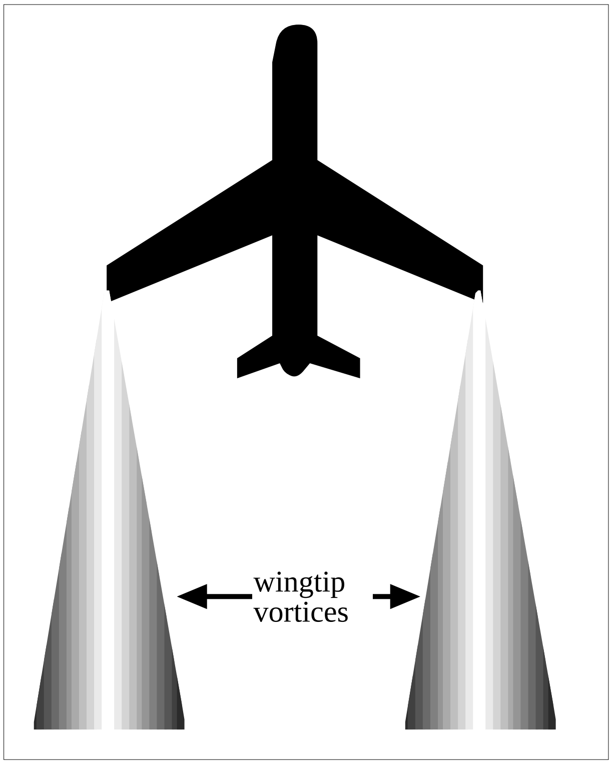


Pressure drag on a wire versus a wing

Another kind of pressure drag occurs at the tips of the wings. This is called **induced drag** because it is caused by, or "induced" by the lift on the wings. Air always wants to move from high pressure to low pressure. Because the air above the wing is at a low pressure, the air wants to "curl up" around the top of the wing. As the wings move through the air, this curling action causes big spirals **(vortices)** of air. these vortices have a lot of kinetic energy. The engines have to produce extra power to overcome the energy that these vortices create. Because these vortices make the engines work harder, impede the motion of the plane, and are caused by the lift, they are often referred to as **drag due to lift.**



Wing tip vortex formation



Two wingtip vortices (induced drag)

These wingtip vortices are the main reason that planes must wait a while between takeoffs. It can be dangerous flying in the vortices of another plane. These same vortices are the reason that birds fly in V-formation. In this case, the birds take advantage of the upwind side of the vortex shedding off the bird in front of them. This updraft actually lifts the bird up, making the flight a little easier.

Blowing Cans

What happens when you blow between two cans?

Materials:

- approximately 25 drinking straws
- two empty soda cans

Instructions:

1. Place the straws on a flat table top, parallel to each other and about 1 centimeter apart.

2. Place the cans upright on the straws, about five centimeters apart.

3. What do you think will happen if you blow air between the cans through a straw? Try it.

What happened?

Why?

Reference:

Jacobs, S. (1994). Whelmers, Volume 1: Science Demonstrations that Spark your Imagination. Wichita, Kansas: Jake's Attic Productions. (Distributed by Sargent-Welch Scientific Company, 1-800-SARGENT).

Blowing on Paper: Two Activities

Blowing on paper can have surprising results.

Blowing Paper off Books

Materials:

paper
two thick books
metric ruler

Instructions:

1. Lay two thick books about 10 cm apart.

2. Place a sheet of paper on the books so that it bridges the gap between them.

3. Try to blow the paper off the books by blowing underneath it.

What happens? Why?

Blowing Sheets of Paper Apart

Materials:

two sheets of paper
` metric ruler

Instructions:

1. Hold two sheets of paper vertically about 5 cm apart.

2. Blow the sheets apart by blowing hard between them.

What happens? Why?

References:

Walpole, B. (1988). 175 science experiments to amuse and amaze your friends. New York: Random House.

The Hovering Card

Blow downwards on a card with surprising results.

Materials:

- index card
- scissors
- metric ruler
- pencil
- thumbtack
- spool
- straw

Instructions:

1. Cut a square 5 cm on each side out of thin cardboard. (An index card is about the right thickness.)

2. Draw diagonal lines connecting the opposite corners. The lines should cross at the center of the card.

3. Carefully push a thumbtack through the point where the lines intersect. Hold the card so that the flat part of the thumbtack is underneath and its point is on top.

4. Place a spool over the point of the tack. Insert a short piece of a straw into the hole on the top of the spool.

5. Blow hard through the straw, then let go of the card.

What happens? Why?

References:

Doherty, P. and Rathjen, D. (1991). The Exploratorium Science Snackbook. San Francisco: Exploratorium Teacher Institute.

Walpole, B. (1988). 175 science experiments to amuse and amaze your friends. New York: Random House.

Blowing on Ping-Pong Balls: Two Activities

Ping-Pong Ball in a Funnel

Can you blow a ping-pong ball out of a funnel?

Materials:

ping-pong ball
funnel

Instructions:

1. Place a ping-pong ball in a clean funnel.

2. Hold the funnel upright and put the narrow end in your mouth.

3. Blow the ball out of the funnel.

What happens?   Why?

Reference:

Churchill, E. R. (1991). Amazing Science Experiments with Everyday Materials. New York: Sterling Publishing Co.

Suspended Ping-Pong Balls

Can you blow two ping-pong balls apart?

Materials:

two ping-pong balls, or other small balls
string
tape
metric ruler

Instructions:

1. Tape a piece of string to each ping-pong ball.

2. Hang the balls at the same level about 5 cm apart.

3. Blow hard between the two balls.

What happens? Why?

Reference:

Walpole, B. (1988). 175 science experiments to amuse and amaze your friends. New York: Random House.

Unrolling Toilet Paper

There's more than one way to get toilet paper off the roll.

Materials:

roll of toilet paper
leaf blower
dowel rod, about two feet long

Instructions:

1. Thread the dowel rod through the toilet paper roll. Unroll about two feet of toilet paper, letting it hang down.

2. Have one person hold the dowel horizontally, with the hanging paper facing away from the leaf blower.

3. A second person should hold the leaf blower. Turn on the leaf blower, directing the stream of air just over the top surface of the roll. What happens?

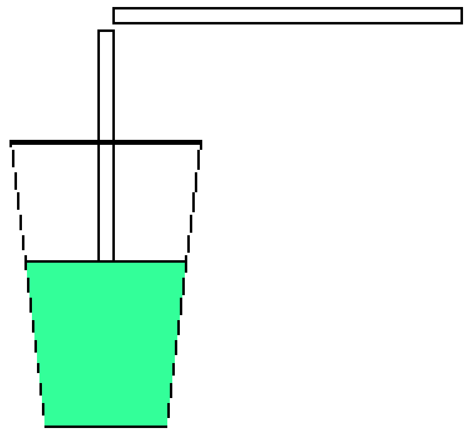
When the leaf blower is turned on, what happens to the pressure above the roll of toilet paper?

Why does the paper unroll?

Reference:

Jacobs, S. (1994). Whelmers, Volume 1: Science Demonstrations that Spark your Imagination. Wichita, Kansas: Jake's Attic Productions. (Distributed by Sargent-Welch Scientific Company, 1-800-SARGENT).

Water Sprayer



How do perfume and plant sprayers work?

Materials:

two straws
drinking glass

Instructions:

1. Hold a straw upright in a glass of water so that the top of the straw projects over the top of the glass.

2. Place a second straw perpendicular to the first so that the end of the second straw is almost touching the opening of the first, but is not blocking it.

3. Blow hard through the second straw.

What happens? Why?

References:

Walker, J. (1977). The Flying Circle of Physics with Answers. New York: John Wiley & Sons.

Walpole, B. (1988). 175 science experiments to amuse and amaze your friends. New York: Random House.

Paper shapes

Materials:

- Index cards or thin cardboard
- ruler
- scissors
- scotch tape
- blow dryer

Instructions:

1. Cut two (or more) index cards into strips about 2 cm wide.

2. Bend one strip into a circle and tape the two ends together.

3. Form the remaining strips into other shapes: square, teardrop, etc.

4. Place the shapes in a row on a table.

5. Place the blow dryer so its air stream will flow along the surface of the table. Turn it on low and try blowing the shapes off the table.

The shapes that shift the most easily have the most drag, or air resistance. Those that move least are the most streamlined.

Which of your shapes had the least drag? Can you design an even more streamlined shape?

Reference:

Herbert, D. and Ruchlis, H. (1968, revised 1983). Mr. Wizard's 400 Experiments in Science. North Bergen, N.J.: Book Lab.

Bouncing Balls

How high can a ping-pong ball bounce?

Materials:

ping-pong ball
golf ball
hard floor

Instructions:

1. Drop the ping-pong ball from about chest height. How high does it bounce?

2. Can you think of other ways to make the ping-pong ball bounce higher? To do so, you must give the ball additional energy. (For example, dropping it from a greater height would increase its potential energy.) How else could you add more energy?

3. Drop the golf ball from the same height. How high does it bounce?

4. Now hold the two balls in one hand at chest height, with the ping-pong ball directly above the golf ball. Drop them. How high does each ball bounce?

When the balls are bounced together, the ping-pong ball must have more energy (since it bounces higher). Where does the extra energy come from?

What about the golf ball? Does it have more or less energy when bounced with the ping-pong ball?

What do you think would happen if you bounced the two balls with the golf ball on top?

What would happen if you bounced two ping-pong balls together?

Reference:

Jacobs, S. (1994). Whelmers, Volume 1: Science Demonstrations that Spark your Imagination. Wichita, Kansas: Jake's Attic Productions. (Distributed by Sargent-Welch Scientific Company, 1-800-SARGENT).

Linked Pendulums

Start a pendulum swinging without touching it.

Materials:

- two chairs (and perhaps books to weigh them down)
- string
- modeling clay

Instructions:

1. Make two balls of modeling clay, each about the size of a ping-pong ball. Attach each ball to a 40-cm-long string.

2. Tie a third piece of string to the backs of two chairs facing away from each other about one meter apart.

3. Tie the two modeling-clay pendulums to the string between the chairs, spacing them evenly. Make sure that the pendulums are hanging at the same level.

4. Hold one pendulum still while you start the other one swinging. Now let go of the first pendulum.

What happens? Why?

At each stage, which pendulum has more kinetic energy?

Is energy conserved in this system (i.e., does the total amount of energy of all types stay the same)?

References:

Doherty, P. and Rathjen, D. (1991). The Exploratorium Science Snackbook. San Francisco: Exploratorium Teacher Institute.

Walpole, B. (1988). 175 science experiments to amuse and amaze your friends. New York: Random House.

Paint-can Pendulum

Materials:

- one-gallon paint can with lid
- sand
- strong rope
- large eye bolt

Instructions:

1. Fill the paint can with sand and close the lid.

2. Attach the eye bolt to the ceiling. Use the rope to suspend the paint can from the eye bolt. The can should hang at about knee level.

3. Pull the can to one side so that it just reaches your nose. Let go, being careful not to push the can or to move.

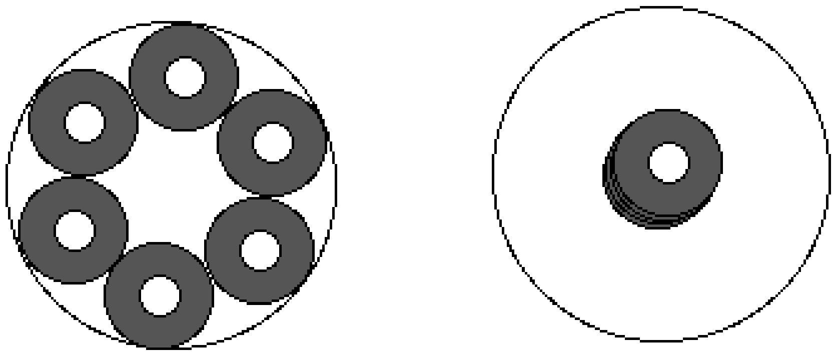
Do you get whacked in the head? Why not (hopefully!)?

At what point is the potential energy of the can the greatest? The kinetic energy?

Reference:

Doherty, P. and Rathjen, D. (1991). The Exploratorium Science Snackbook. San Francisco: Exploratorium Teacher Institute.

Velcro Cans



Materials:

- two identical cookie tins with lids
- adhesive-backed hook-and-loop fasteners
- ten large metal washers
- a board to serve as a ramp

Instructions:

1. Using the velcro, attach five washers to the inside of each can. In one can, stack the washers in the middle of the can. In the other, arrange them evenly around the perimeter of the bottom of the can.

2. Put the lid on each can. Place the cans on their sides at the top of a ramp.

3. Release the cans at the same time, being careful not to give either one a push.

Which can reaches the bottom first? Why do you think this happened?

Since the two cans started with the same amount of potential energy, why didn't they finish in a tie?

Try other arrangements of washers. Which ones are faster?

Reference:

Doherty, P. and Rathjen, D. (1991). The Exploratorium Science Snackbook. San Francisco: Exploratorium Teacher Institute.

Ball in an Air Stream

Suspend a ping-pong ball in a stream of air.

Materials:

- blow dryer
- ping-pong ball

Instructions:

Hold a blow dryer so that the air stream is directed straight up.

Place a ping-pong ball in the air stream.

Once the ball is suspended, try pulling it a little to one side and letting go.

What happens? Why?

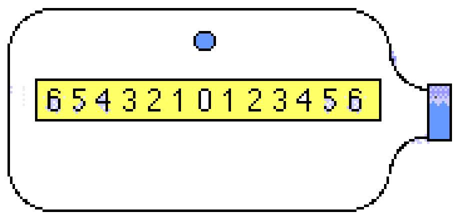
References:

Doherty, P. and Rathjen, D. (1991). The Exploratorium Science Snackbook. San Francisco: Exploratorium Teacher Institute.

Walker, J. (1977). The Flying Circle of Physics with Answers. New York: John Wiley & Sons.

Bottle Forcemeter

Use a soda bottle to measure balanced and unbalanced forces.



Materials:

- two-liter plastic soda bottle with lid
- masking tape
- permanent marker
- meter stick
- food coloring

Instructions:

1. Fill the bottle full of water and add a couple of drops of food coloring. Adjust the water level so that when the bottle is capped and laid on its side, it contains one air bubble, about the size of a nickel.

2. Put the bottle on a level surface. Tap on the bottle until the air bubble comes to rest.

3. Attach a strip of masking tape along the length of the bottle. Make a mark on the tape above the air bubble and label that mark “0.”

4. From the zero mark, draw marks on the tape in both directions, one centimeter apart. Number them 1, 2, 3, ... in each direction.

5. When your bubble is at zero, the forces on your bottle are balanced. If the forces are not balanced, the bubble will show you the size and direction of the net force.

Try moving your bottle to the right or left at different speeds. What happens?

Try moving your bottle at a constant speed. Where is the bubble located?

What happens if you speed up or slow down?

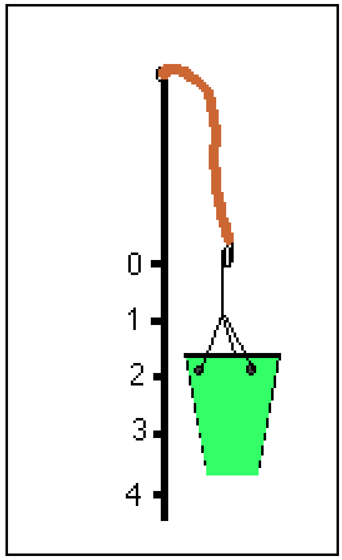
What happens if you spin the bottle?

References:

American Chemical Society/American Institute of Physics (May 1992). WonderScience volume 6, number 5: Forces.

Do-it-yourself Spring Scale

Make a spring scale and use it to measure the force of gravity.



Materials:

- shoe box with lid
- two paper clips
- rubber band
- string
- paper cup
- marker
- white paper
- tape
- metric ruler
- nail
- pennies

Instructions:

1. Tape white paper to the lid of the shoe box. Draw a straight line lengthwise down the center of the lid. Punch a hole on the line near one end of the lid.

2. Cut the rubber band and thread one end through the hole in the lid. Tie one of the paper clips on the end of the rubber band

inside the lid to keep the rubber band from sliding through the hole.

3. Tape the lid to the box. Tie the second paper clip to the other end of the rubber band.

4. Punch three holes in the cup near the rim, evenly spacing the holes around the rim. Thread a string through each hole. Tie a knot in each string so that it does not pull through the hole. Tie the other ends of the three strings together a few centimeters above the cup so that the cup hangs evenly.

5. Tie a fourth piece of string to the knot holding the other three. Attach the other end of the string to the paper clip on the rubber band.

6. Hold the box upright, tilted forward slightly so the cup swings freely. Mark the center line on the box level with the bottom of the paper clip. Mark it "0."

7. Draw marks below the zero mark at one cm intervals. Number them 1, 2, 3, and so on.

8. You can use your spring scale to measure to force of gravity upon any object you put in the cup.

Try putting a few pennies in your cup. If you double the number of pennies, does the force double?

What happens to the force reading as you drop the box? Why?

References:

American Chemical Society/American Institute of Physics (May 1992). WonderScience volume 6, number 5: Forces.

Walpole, B. (1988). 175 science experiments to amuse and amaze your friends. New York: Random House.

Dropping Things

You’ve probably heard of Galileo dropping objects from the Leaning Tower of Pisa to show that all objects fall at the same rate, regardless of their weight. You probably also know from experience that objects don’t fall at the same rate. The discrepancy is due to air resistance. In a vacuum, all objects do fall at the same rate. The following activities will help you examine the opposing forces of gravity and air resistance.

Materials:

book
sheets of paper
sugar cube
die
ball bearing
marble
other pairs of objects of the same size and shape but different weights

Instructions:

1. Choose a pair of objects of the same size and shape but different weights. Hold them at the same height and drop them at the same time. Do they hit the ground at the same time?

2. Cut a sheet of paper so that it has the same length and width as the book. Hold the two objects horizontally at the same height and drop them together. The book should fall faster. Now place the sheet of paper on top of the book and drop them again. Does the paper fall as fast as the book?

3. Take two identical sheets of paper. Crumple one into a tight ball. Leave the other flat. Hold the flat sheet horizontally. Hold the crumpled sheet at the same height. Drop them together. Since the sheets are the same, the difference in their falling speed is due to the differing air resistances of their shapes.

References:

Doherty, P. and Rathjen, D. (1991). The Exploratorium Science Snackbook. San Francisco: Exploratorium Teacher Institute.

Walpole, B. (1988). 175 science experiments to amuse and amaze your friends. New York: Random House.

Wood, R. W. (1992). Science for Kids: 39 Easy Engineering Experiments. Blue Ridge Summit,PA: TAB Books (a division of McGraw-Hill).

Using Spring Scales

Spring scales can be used to measure forces.

Materials:

- two spring scales
- string
- board
- several books
- wood block with nail or screw for attaching spring scale
- wax paper
- sandpaper
- bath towel
- aluminium foil

Instructions:

1. If an object does not move, the forces acting upon it must be balanced. If I pull on something and it does not move, then an equal and opposite force must be acting on it. (For example, if I pull on a heavy piece of furniture and it does not budge, then the friction between it and the floor must be counteracting my force.) To demonstrate these opposing forces, tie the top of a spring scale to an immovable object.

2. Attach the hook of the spring scale to the hook of a second spring scale.

3. Pull on the second spring scale. Read the force that is measured by each spring scale. Are they the same?

4. What would happen if you used your double spring scales to drag an object? Try it. What force registers on each scale?

5. You can also use a spring scale to measure friction. Make a ramp from a board and some books.

6. Attach a spring scale to a block of wood. Drag the wood up the

ramp by pulling on the spring scale. What does the scale register?

7. Cover the ramp with wax paper. Drag the block up the covered ramp. Is the amount of force used different on the wax paper than on the plain ramp?

8. Repeat the experiment using aluminium foil, sandpaper, a bath towel, or other materials.

Which materials require you to use the most force in dragging the block? The least?

How is the force used related to friction?

Make a graph of your results.

References:

Lowery, L. (1985). The Everyday Science Sourcebook: Ideas for Teaching in the Elementary and Middle School. Palo Alto, CA: Dale Seymour Publications.

Walpole, B. (1988). 175 science experiments to amuse and amaze your friends. New York: Random House.

Paper Wing

Make an airplane wing out of paper.

Materials:

- paper
- scissors
- metric ruler
- tape

Instructions:

1. Cut a sheet of paper about 10 cm by 20 cm.

2. Fold the paper in half widthwise.

3. Tape one short edge of the paper about 3 cm above the other short edge.

4. Insert the ruler inside the paper "wing," with the edge of the ruler resting against the fold.

5. Hold the ruler so that the folded edge of the wing is facing you. Blow hard at the fold.

What happens? Why?

References:

Walpole, B. (1988). 175 science experiments to amuse and amaze your friends. New York: Random House.

Balloon in a Bottle

Can you blow up a balloon in a bottle?

Materials:

two one-liter soda bottles
two balloons with wide openings
nail

Instructions:

1. Using the nail, punch a small hole in one of the bottles, about five centimeters from the bottom.

2. Insert an uninflated balloon into each bottle, stretching the opening of the balloon over the mouth of the bottle. Do you think wou will be able to blow up the balloons inside the bottles? Why or why not?

3. Try blowing up the balloons. What happens? Can you explain your results in terms of air pressure?

4. Now fully inflate the balloon inside the bottle with the hole. When you are done, hold your finger over the opening. What do you think will happen when you remove your finger? Try it.

5. Inflate the balloon again, holding your finger over the hole. Now fill the inflated balloon with water. If you remove your finger, do you think the increase in air pressure as the air enters the hole will be strong enough to push the water out? Try it and see.

Reference:

Jacobs, S. (1994). Whelmers, Volume 1: Science Demonstrations that Spark your Imagination. Wichita, Kansas: Jake's Attic Productions.

(Distributed by Sargent-Welch Scientific Company, 1-800-SARGENT).

Blowing through a Funnel

Blowing through each end of a funnel can demonstrate differences in air pressure.

Materials:

- clean funnel
- candle in candle holder
- matches

Instructions:

1. Make sure that the candle is firmly secured in the candle holder or is otherwise stable.

2. Light the candle.

3. Put the narrow end of the funnel in your mouth and try to blow out the candle. Can you do it?

4. Now turn the funnel around. Try to extinguish the candle by blowing through the wide end. What happens?

Which position made it easier to blow out the candle? Why?

For each position of the funnel, where was the pressure highest? Where was it lowest?

Reference:

Wood, R. W. (1992). Science for Kids: 39 Easy Engineering Experiments. Blue Ridge Summit,PA: TAB Books (a division of McGraw-Hill).

The Burping Funnel

Materials:

- Erlenmayer flask
- one-hole stopper to fit flask
- long-stemmed glass funnel
- food coloring
- glycerin

Instructions:

1. Carefully insert the stem of the funnel into the hole of the stopper. It is best to coat the end of the stem with glycerin before inserting it. (The glycerin allows the stem to slide in easily without breaking.)

2. Insert the stopper into the flask so that the funnel is above the flask. Pour colored water into the funnel.

3. The funnel should begin to "burp." If the water does not flow down into the flask, try jiggling the flask to get it started. If the water flows smoothly without burping, make sure that the stopper is making a tight seal with the flask.

Why does the can burp instead of flowing smoothly?

At each stage of the burp, is the pressure greater inside the flask or outside?

A similar phenomenon can be seen when pouring liquid out of any container with a narrow opening. Why do people punch two holes on opposite sides of large juice cans?

The Heavy Paper

Materials:

- ruler
- large sheet of paper
- table or other flat surface

Instructions:

1. Position the ruler so that about two-thirds of it is on the table and the remaining third is hanging over the edge.

2. Lay the sheet of paper on the table over the ruler.

3. Hit the overhanging end of the ruler with a downward motion.

Can you make the paper fly into the air?

What happens if you change the size of the paper?

Explain your results in terms of pressure.

Reference:

Walpole, B. (1988). 175 science experiments to amuse and amaze your friends. New York: Random House.

Lifting Cups

Can you lift two cups without touching them?

Materials:

two cups
balloon

Instructions:

1. Can you figure out a way to lift the cups without touching them, using only the balloon?

2. Here's the answer: Place the cups on their sides, about 2 centimeters apart, with the rims facing each other.

3. Place the uninflated balloon between the two cups. Slowly blow up the balloon. It will push the cups apart.

4. Lift the balloon. The cups will come too.

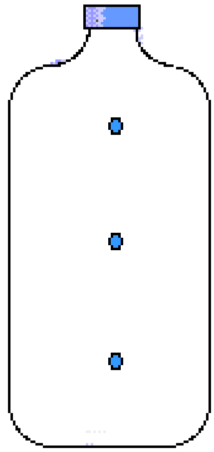
Why do the balloons "stick" to the cup?

(Hint: What happens to the air inside the cup as you inflate the balloon? How does the air pressure inside the cup change when you pull on the balloon?)

Reference:

Jacobs, S. (1994). Whelmers, Volume 1: Science Demonstrations that Spark your Imagination. Wichita, Kansas: Jake's Attic Productions. (Distributed by Sargent-Welch Scientific Company, 1-800-SARGENT).

Pressure Bottle



Materials:

one-liter soda bottle with three small holes punched in it as shown
bottle cap
three push pins
large shallow pan to hold bottle

Instructions:

1. Fill the bottle with water but do not cap it. Remove the middle pin. Does any water come out?

2. Now screw the lid on tightly. Does water come out now?

3. Loosen the cap. What happens? Why does capping the bottle make a difference?

4. Replace the middle pin and refill the bottle. Cap it. Take out the middle pin and squeeze the bottle. Does water come out?

5. Squeeze hard and then lightly. How does the strength of your squeeze affect the stream of water?

6. When you stop squeezing, watch the hole carefully. What happens? Why do you think this happens?

7. Replace the middle pin and refill the bottle. Remove all three pins and the cap. How do the three streams of water differ? Make a sketch of the bottle and the streams below.

8. Watch your bottle for a few minutes. As the level of the water goes down, how do the streams change? Why do you think this happens?

9. Replace all three pins and refill the bottle. Cap it. Now remove any two of the pins. What happens?

10. Now try two other pins. Try all of the combinations. Is there any difference between taking the top and bottom pins out and taking the middle and bottom pins out? Describe the difference. What do you think causes this difference?

Adapted from an activity by Michael Fox, Shady Hill School

Reference:

Wood, R. W. (1992). Science for Kids: 39 Easy Engineering Experiments. Blue Ridge Summit,PA: TAB Books (a division of McGraw-Hill).

Balancing Meter Stick

Materials:

meter stick
two rubber bands
several identical metal washers
two paper clips

Instructions:

1. Hold the meter stick horizontally, resting it on your two outstretched index fingers, one at each end of the stick.

2. Slowly move your two fingers towards each other. When your fingers meet, the ruler should still balance. This point on the meter stick is called its *center of gravity*. Notice that your fingers do not move smoothly. The finger that is closer to the center of gravity has more weight on it, so it does not move as easily. Once the other finger gets closer, the situation reverses and the first finger begins to slide.

3. Now wrap a rubber band around each end of the meter stick. Bend each paper clip into an “s” shape and hang one clip from each rubber band.

4. Try finding the center of gravity of your meter stick again. Is it in the same place (or almost the same place)? Why or why not?

5. Now place washers on the hooks. If you add the same number of washers, does the meter stick balance in the same place? What happens if you use different numbers of washers?

6. Try moving one of the rubber bands closer to the center. What happens?

7. Can you find a way to place the rubber bands so that different numbers of washers on each side will balance?

Can you figure out the relationship between the position of the rubber band (distance from the center) and the number of washers (force)?

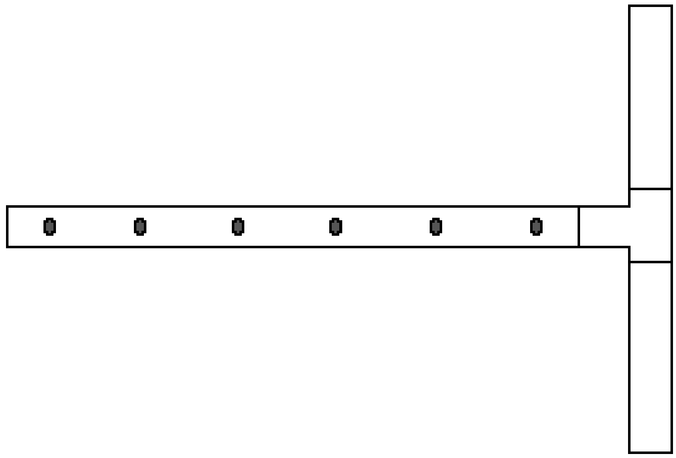
How is this related to torque?

Can you explain what is happening in terms of the equations for torque?

Reference:

Doherty, P. and Rathjen, D. (1991). The Exploratorium Science Snackbook. San Francisco: Exploratorium Teacher Institute.

Torque Tester



Materials:

two-inch-wide plastic pipe, one piece three feet long and two pieces one foot long each
"T" joint to fit the pipe
plastic pipe adhesive
six threaded eye bolts with nuts
electric drill
old window sash weight or other two-to-five pound weight
snap hook for attaching weight

Instructions:

1. Glue the pipe pieces and the T joint together to form a T.

2. Drill six evenly spaced holes in the longest section of pipe, putting the first and the sixth holes near the ends of the pipe.

3. Put an eye bolt in each hole, securing it with a nut.

4. Attach the snap hook to the weight.

5. Use the snap hook to attach the weight to the eye bolt nearest the T handle. Grasp the handles (the shorter pipe sections) and lift the bar.

6. Now try moving the weight to another eye bolt and lifting the

bar. What happens?

7. Try the other positions.

Which position is easiest? Which is hardest:?

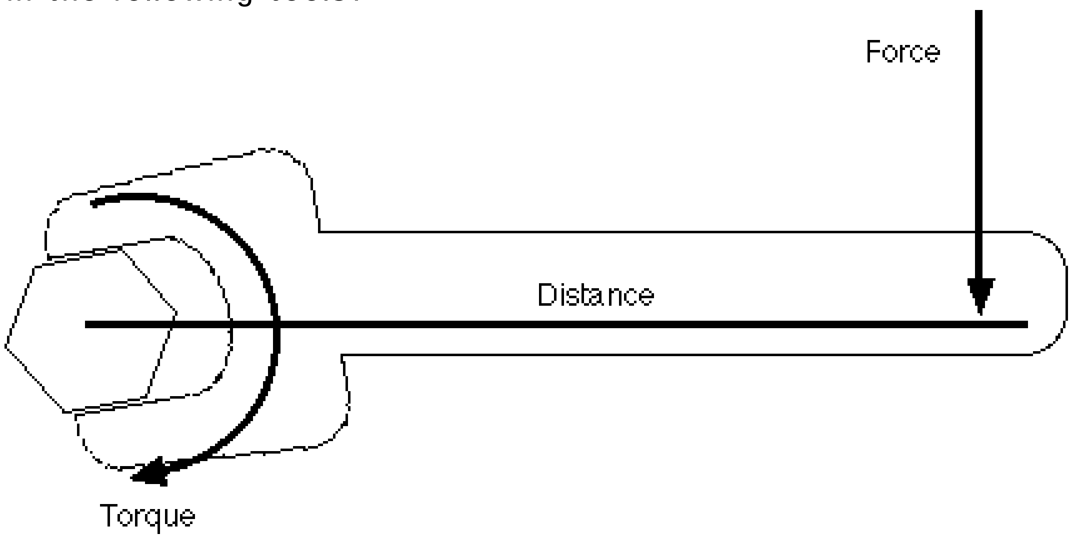
Can you explain what is happening in terms of the equations for torque?

Reference:

Jacobs, S. (1994). Whelmers, Volume 1: Science Demonstrations that Spark your Imagination. Wichita, Kansas: Jake's Attic Productions. (Distributed by Sargent-Welch Scientific Company, 1-800-SARGENT).

Torque Tools

Many tools make use of torque. Can you identify how torque is being used in the following tools?



Materials:

wrenches of various sizes and types
nuts and bolts that fit the wrenches
a board with holes for attaching bolts (and screws)

As many of these tools as possible/practical:
screwdrivers and screws
hammer
shovel
spade
scissors
punch-type can opener
nutcracker
garlic press
stapler
tongs

Instructions:

1. Try using the wrenches to loosen and tighten the nuts. Does the amount of force you apply make a difference? Does the length of the wrench handle make a difference?

2. Try the other tools. How do they involve torque?

Try drawing a force diagram for one of the other tools, similar to the wrench diagram above.

Reference:

Rogers, C., et al. Toying with Torque: A Teacher's Guide.

Quarter Flick

If you shoot a bullet out of a gun and, at the same moment, drop another bullet, which bullet will hit the ground first? (In the interests of safety and practicality, we'll answer this question using quarters.)

Materials:

- two quarters
- a table

Instructions:

1. Position both quarters so that they are overhanging the edge of the table, a few centimeters apart.

2. At the same moment, flick one of the quarters hard with the fingers of one hand while gently pushing the other quarter off the edge of the table with the other hand. (This may require a little practice.)

3. Notice which quarter hits the ground first. Repeat the experiment several times so that you are fairly sure of your results.

Which quarter hits the ground first? Is this what you expected?

Remember that velocity has two components, speed and direction. In this experiment, we are comparing the velocity of the two coins in the downward direction only. (Clearly, the flicked coin has a greater horizontal velocity.) What force is causing the change in vertical velocity of each quarter?

Is the downward force acting on each quarter the same?

What does that imply about their downward velocities?

Snail Trails

Just how fast (or slow!) does a snail crawl? Remember that velocity has two components, speed and direction. In this experiment, we will try to measure the speed of snails.

To find the average speed of a snail, you need to know the time it spent crawling and the distance it crawled. Measuring the time is easy. Measuring the distance is harder--snails rarely crawl in straight lines.

Materials:

land snails
glass or plastic plates
wax pencils
clock with second hand or stop watch
meter stick
string

Instructions:

1. Gently place the land snail on a glass plate. Hold the glass plate horizontally in one hand. Wait until the snail settles down and begins to crawl.

2. Start timing the snail. As the snail crawls, trace his movements on the underside of the glass plate with a wax pencil.

3. After two minutes (or some other reasonable amount of time), stop timing and tracing. Take the snail off the galss plate.

4. Lay the string on top of your wax trail, following each curve as closely as possible. When you are done, cut the string at the end of the trail.

5. Your string should now be the same distance long as the snail's trail. Measure the string using the meter stick.

6. To find the snail's speed, divide the distance it crawled by the amount of time it spent crawling.

7. Figure out the units that you used to report your snail's speed. (Miles per hour? Centimeters per second?)

How fast did your snail go? How does its speed compare with that of the other snails?

Make a bar graph showing the speeds of the snails. What is the average speed for all the snails?

Materials:

Snails are available from Connecticut Valley Biological (1-800-628-7748) or other biological supply companies.